GEOLOGY

SAN DIEGO COAST REGIONAL COMMISSION

CALIFORNIA COASTAL ZONE CONSERVATION COMMISSION

SUMMARY OF THE REPORT

COASTAL GEOLOGY AND GEOLOGICAL HAZARDS

San Diego Coast Regional Commission

Conservation Soil S. Dieg

Emergency relief Earthquakes

The California Coastal Zone Conservation Act of 1972 (Proposition 20 at the election of November 7, 1972) created the California Coastal Zone Conservation Commission and six Regional Commissions, and directed them to prepare a comprehensive, enforceable plan for the preservation, protection, restoration, and enhancement of the coastal zone.

This report is the summary of one of a series of background reports designed to help the San Diego Coast Regional Commission carry out this responsibility. Using these reports, the San Diego Coast Regional Commission will develop recommendations to the California Coastal Zone Conservation Commission on statewide policy to this Region. Each report focuses on a specific aspect of the Coastal Zone. The recommendations contained in these reports, together with the recommendations of the other five Regional Commissions, will comprise the basic materials used in planning the future of the California coast.

This summary report was prepared by the Commission staff to focus on the most important coastal planning considerations, as suggested in the more extensive technical report. Possible planning recommendations based on the technical report are included with the summary. These are only tentative, since the conclusions based on this report will need to be considered after other reports on different aspects of the coastal zone have been completed.

SAN DIEGO COAST REGIONAL COMMISSION
6154 Mission Gorge Road, Suite 220
San Diego, California 92120

February 19, 1974

DRAFT - NOT FOR PUBLICATION

77 04204

SUMMARY

COASTAL GEOLOGY AND GEOLOGICAL HAZARDS

INTRODUCTION

The California coast is a part of one of the most geologically active regions in the world. From a geologic time frame, there is little permanence to the California coastal landforms. While it may take millions of years to reshape the coast, many geologic events can be perceived by man and are often experienced as natural disasters. Earthquakes, landslides, tsunamis, beach erosion, and cliff erosion are five such events.

In relation to the rest of the California coast, the San Diego section has been relatively stable during recorded history. This may mean that the San Diego coastal plain is, in fact, relatively stable but geologic investigations are far from complete. New information may reveal that the coastal plain is much more active than recent history has indicated.

FAULT ZONES

Relative to other regions on the circum Pacific Seismic belt, the San Diego coast has a low to moderate seismic rating. The coastal area has experienced only 3 damaging earthquakes since 1812. On December 8, 1812, a large shock destroyed the mission at San Juan Capistrano and was strongly felt in San Diego; on February 23, 1892 a major event centered in northern Baja California cracked many masonry walls in San Diego and some in Santa Ana; and some brick walls in San Diego were cracked in the October 23, 1894 shock.

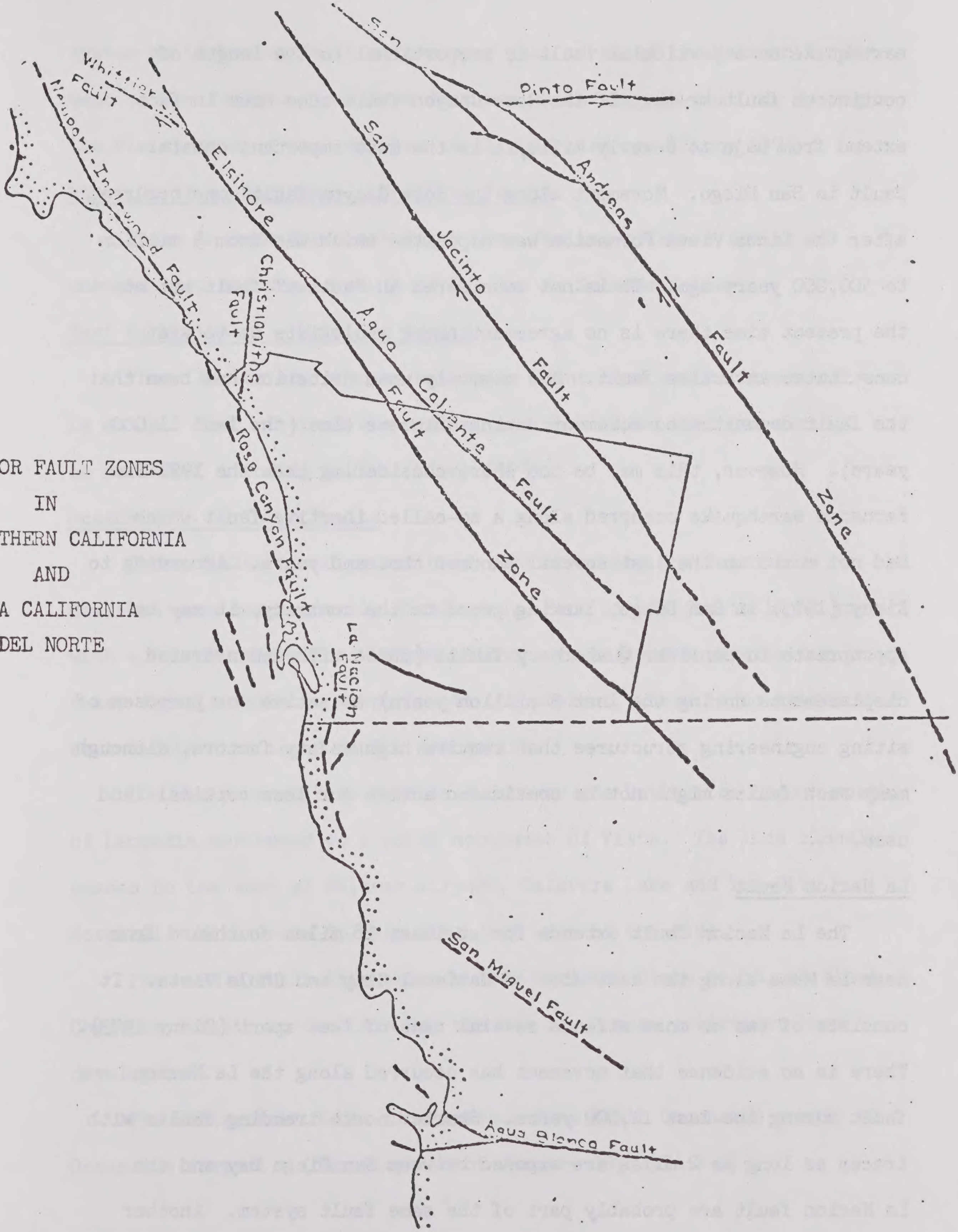
San Diego's coastal plain is a relatively stable area broken by only two fault systems (Figure 1). One consists of a series of discontinuous north to northwest striking faults that are usually steeply dipping and have normal separation. The other subordinate system consists of east to northeast striking faults which generally have much smaller separations and occur northeast of La Jolla and on the Point Loma peninsula. The largest northwest trending fault zone is the Rose Canyon fault zone which consists of a number of closely spaced parallel faults. Whether or not these seemingly discontinuous faults actually comprise one continuous fault is impossible to determine at this time. It does appear that there is a zone of faulting extending from a point inland from Ensenada through Newport Beach to Beverly Hills.

Rose Canyon Fault Zone

An on-shore section of the Rose Canyon fault zone can be traced for more than 10 miles from La Jolla to downtown San Diego. But marine geophysical studies of sea-floor geologic structure suggest that the Newport-Inglewood and Rose Canyon faults may be part of a single zone of faulting which lies no more than 6 miles offshore between Newport Beach and La Jolla. A recent study by Moore (1972) indicates that the Rose Canyon fault extends offshore and northward from La Jolla to a point a few miles west of Oceanside. In addition, a number of geologists speculate that this fault zone (Newport-Inglewood to Rose Canyon) connects with the active San Miguel fault, whose northern end lies about 90 miles southeast of San Diego. Although no historic shocks are known to have originated on the Rose Canyon fault, it has apparently undergone vertical movement approaching 100 feet during the past 100,000 years (Moore, 1972). It has been determined that the maximum probable

FIGURE 1

MAJOR FAULT ZONES
IN
SOUTHERN CALIFORNIA
AND
BAJA CALIFORNIA
DEL NORTE



Source: CPO, 1973 "Initial Coastline Study and Plan", p.60.

earthquake on a particular fault is proportional to the length of continuous fault break. If the Rose Canyon fault zone does in fact extend from Baja to Beverly Hills, it is the most important coastal fault in San Diego. Movement along the Rose Canyon fault zone occurred after the Linda Vista Formation was deposited which was from 3 million to 500,000 years ago. It is not considered an "active" fault but at the present time there is no agreement among geologists as to what constitutes an active fault. One commonly used criterion has been that the fault demonstrates movement during Holocene time (the last 11,000 years). However, this may be too short considering that the 1971 San Fernando earthquake occurred along a so-called inactive fault which had not moved in the last several hundred thousand years. According to Ziony (1973) in San Diego, lacking proof to the contrary, it may be appropriate to consider Quaternary faults (those with demonstrated displacements during the last 3 million years) as active for purposes of siting engineering structures that require high safety factors, although many such faults might not be considered active for less critical land uses.

La Nacion Fault

The La Nacion fault extends for at least 16 miles southward from near La Mesa along the east side of National City and Chula Vista. It consists of two or more strands several tens of feet apart (Ziony 1973). There is no evidence that movement has occurred along the La Nacion fault during the last 11,000 years. Shorter north-trending faults with traces as long as 2 miles are exposed between San Diego Bay and the La Nacion fault are probably part of the same fault system. Another group of north-trending faults which probably also belong to the same

system as La Nacion fault were mapped just north of the Mexican border west of San Ysidro. Some have features which suggest faulting during the Pleistocene, from 3 million to 11,000 years ago (Ziony 1973).

Other North to Northwest - Striking Faults

These include the Short Point Loma faults, offshore faults of unknown age, and faults south of Del Mar in Soledad Valley.

East to Northeast - Striking Faults

These faults are exposed mainly on Point Loma and northeast of La Jolla. Most of these are smaller and much older than the north to northwest trending faults (Ziony 1973).

Oceanside - Carlsbad Faults

Three faults trending northeast and bisecting the Oceanside-Carlsbad area were recently discovered. Each of the faults lines up with a branch of the Rose Canyon offshore fault system paralleling the coast from La Jolla to Newport. At the present, there is no evidence to indicate that these faults are active.

The easternmost line reaches from near the Batiquitos Lagoon north of Leucadia northward to a point northwest of Vista. The line closely passes to the west of Palomar Airport, Calavera Lake and Tri-City Hospital. Mira Costa College lies just west of the line.

The middle fault line extends from Carlsbad State Beach, at about Chestnut Street, to San Luis Rey and the new Oceana retirement home development.

The westernmost fault line reaches from South Oceanside nearly to Oceanside Airport. (San Diego Union January 18, 1974:B-3).

Cristianitos Fault

The Cristianitos fault is a continuous, north trending fault which extends inland from the coast for nearly 11 miles. This fault is clearly exposed in a small canyon approximately 3,000' south of the San Onofre Nuclear plant.

Offshore Faults

According to Moore (1969) the California Continental Borderland is comprised of two sets of faults, a northwest trending set and an east-northeast set. The San Clemente Island fault is the dominant fault. It extends from San Clemente Island south to Cabo Colnett in Baja. In 1951 an earthquake of magnitude 5.9 occurred off the tip of the island.

Earthquake Hazards

While the hazard of ground rupture is geographically limited to fault zones, other earthquake induced hazards would have a much more serious impact. The most potentially hazardous earthquake induced effect on the San Diego coast would be ground shaking. Sites particularly vulnerable to ground shaking are non-engineered fills, unconsolidated alluvial deposits, deep sands, steep unstable hillsides, bay muds, and bay fills. Such conditions are typical on property adjacent to the coastal lagoons, San Diego Bay and Mission Bay; Shelter Island, Harbor Island and much of Coronado which are bay fill property; sections of Oceanside, Solana Beach, Del Mar, Mission Beach, and Imperial Beach which are on top of deep sand. Future construction on all sites in these categories within the coastal zone must be subject to stringent earthquake safety requirements and regulations.

Between the level of extreme hazard and the level of minimum risk, i.e. where there is underlying rock or soil of unquestioned stability, there is a wide range of risk conditions (to date only crudely categorized) which call for a comparable range of constraints on use and construction.

Present seismic regulations in California are inadequate. Understandably, concern about earthquake safety has initially been focused on identification of active faults and their traces. This is the focus of the Alquist-Priolo Geologic Hazards Zones Act of 1972, which provides for the mapping of active fault zones "to aid in land-use planning," and regulating land-use along fault traces. As noted above, however, earth-shaking during a seismic event is frequently more intense at a point remote from the fault trace than along the trace itself. Clearly, earthquake safety considerations must be redirected to a close analysis of specific site conditions.

In this regard, the Uniform Building Code might be expected to provide adequate safeguards. Unfortunately, this is not the case. In the first place, application of the UBC is not uniform, its adoption by local governments has not been mandatory, and in fact local jurisdictions have been notably reluctant to embrace all of its provisions. In the second place, provisions of the UBC for safeguards against earthquake or other geologic hazard are minimal.

In view of the presently random and insufficient attention accorded by local governments in California to the problems of earthquake and geologic hazards in land use and construction, this plan endorses the recommendation of the Joint Committee on Seismic Safety

to require adoption of the UBC by all local jurisdictions and to expand provisions of the Alquist-Priolo Act to include all geologic hazards. Beyond that, however, it is apparent that geologic site analysis should also be mandatory and that competent review be required.

LANDSLIDES

The causes of landsliding can be related to the inherent physical and chemical properties of the rocks and their geologic setting. The inherent properties of rocks that make them "landslide prone" include structural configuration, low strength, presence of minerals possessing perfect cleavage, swelling, and orientation of bedding planes and joints.

A joint can be defined as a fracture in rock, generally more or less vertical. Certain cracks which are oriented so as to divide the rocks into well defined blocks can be termed joint sets. Many of the rock units occurring in the coastal region are fractured and have very distinct joints. The orientation of fractures and plates, and the physical characteristics of the rock are conducive to failure by landsliding. These factors contribute to many of the landslides in Point Loma and Sunset Cliffs as well as those near Torrey Pines State Park. The joint pattern can be most clearly seen at the tip of Point Loma near the Coast Guard Station where the rocks occur in steps rising from the beach.

Many of the coastal rock units contain clayey strata. Erosion of these softer layers, especially by wave action, contribute to slope instability. This particular phenomenon is most easily

seen in portions of the Del Mar formation, particularly in the cliff near Sea Cliff County Park in Encinitas. Where bedding is steep, erosion may be accelerated, especially where grading activities have over-steepened the slope, so that the bedding dips outward and downslope from an excavated slope at a degree less than the slope itself.

External conditions that cause landslides include gravity, erosion, rainfall and seismic activity. Above much of the California shoreline, wave action produces steep cliffs which are subject to recurring landslides.

The California Division of Mines and Geology projects a total statewide loss due to landsliding of almost $10 billion in California between 1970 and the year 2000 (Bull, 198, 1973:8). The only landslide which has caused property damage on the San Diego coast was the 1961 Mt. Soledad slide. However, the reason why property loss in San Diego has been minimal is because development has been sparse in the landslide prone areas. The Rose Canyon Shales, so common on the north county coast, are particularly vulnerable to landsliding, especially on steeply sloped cliffs (Kissling, 1974). As development occurs in these vulnerable areas, the hazard of landslides will increase.

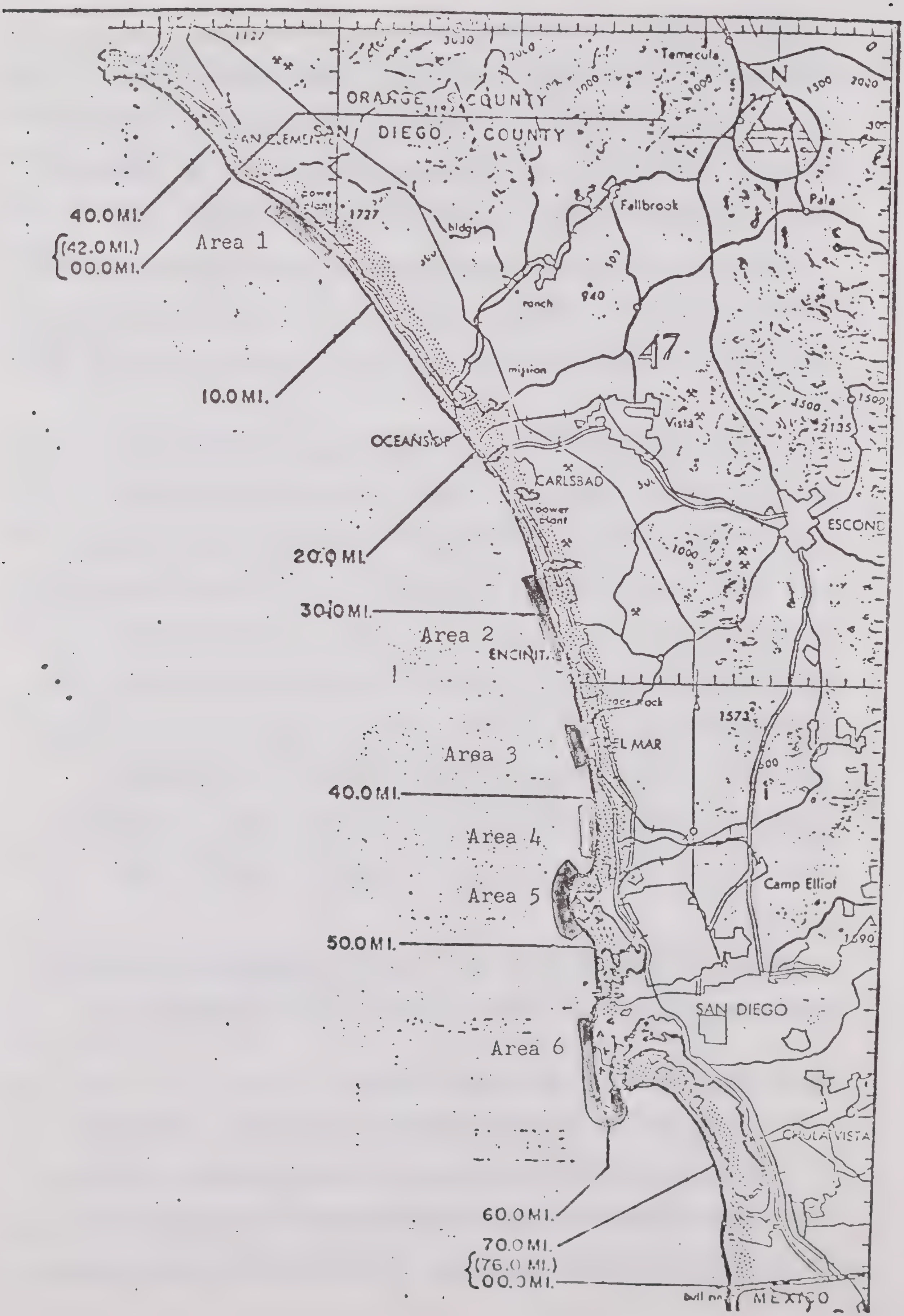
Six areas on the San Diego coast have been identified as particularly hazardous. These are mapped in Figure 2 and discussed below.

<u>Area 1</u> from mile 3.5 to mile 8 San Onofre

This is an area of extensive landslides due mainly to the fact that this region is underlain by the Capistrano Formation, a formation composed of poorly consolidated mudstone and siltstone, soft and easily eroded. This is the type of rock which is easily undercut

FIGURE 2

SIX HAZARD AREAS ON THE SAN DIEGO COAST



by wave action, and as long as the waves can reach these cliffs, there will continue to be landsliding.

Area 2 mile 28 to mile 31.1 Leucadia, Encinitas

This area is underlain by sandstones which have interbeds of clay and siltstone. The rocks are also fractured and this structural feature combined with erosion of the clay seams in the rock has led to undercutting of the cliffs and subsequent slope failures. Runoff from the surface has caused slumping of the overlying terrace deposits. Runoff can be controlled, but unless wave action on the cliffs can be prevented, the area will continue to present the geologic hazard of landsliding (Lough, 1973).

Area 3 mile 36.5 to mile 38 Del Mar

This area presents the same geologic hazards as area 2. The Del Mar Formation which underlies much of the cliffs has closely spaced joints which combined with erosion of the clay seams found in this unit lead to the same problems; undercutting by wave action and slope failure.

Area 4 mile 40.2 to mile 43.1 Torrey Pines

This section of the coast is underlain by the Ardath Shale, a unit which is soft, easily eroded and fails by landsliding when the slopes are oversteepened by wave action. The presence of several faults in this section may contribute to the instability of the cliffs.

Area 5 mile 44.5 to mile 49 La Jolla

This area is underlain by the Point Loma Formation, a unit which by its physical nature is quite resistant to erosion. However, the unit contains many fractures and joints which permit wave action to form caves, enlarge them, and eventually destroy them. Erosion by wave action tends to weaken large blocks of rock which eventually drop off the cliffs and are removed (Moore, D., 1954).

Area 6 mile 53.5 to mile 62 Sunset Cliffs, Point Loma

The problems of this area are similar to those in La Jolla. The area is underlain by the fractured and jointed Point Loma Formation. Sea caves are formed and destroyed and cliff retreat is found to occur due to failure of large blocks of rock loosened along joint sets (Kennedy, 1973a). Sunset Cliffs, being near a residential area, has been cause for much public concern, but the same processes are going on all along the west side of Point Loma and the only reason there is less concern is that it is part of a military reservation and is unpopulated.

Regulations for controlling development of landslide-prone areas exist very randomly and are seldom explicit, because official concern tends to focus on earthquake hazard. Landslide hazard is primarily seen as merely ancillary, since earthquakes frequently trigger landslides. As traditionally with earthquakes, local jurisdictions normally adopt specific landslide regulations only after disaster has struck.

Chapters 29 and 70 of the Uniform Building Code, dealing with foundations and grading, are generally regarded as providing minimal protection against geologic hazards, according to the Final Report to the Legislature of the Joint Committee on Seismic Safety (January 1974, p. 139). This report recommends an updating and strenthening of these provisions and their statewide application. It also proposes State financial and/or geotechnical aid to local governments (p. 140).

The prevention and correction of landslides involves a three part process:

- Determination by surface mapping, trenching, shallow-hole drilling, and laboratory analysis of rocks and soils of such factors as yield-strength, water content, porosity, sheer stress, etc.

- Determination of degree of hazard and if it is possible to stabilize.

- Determination of the method of containment by structural engineers and engineering geologists. Methods used may include cuts, fills, retaining structure (including riprap on the face), pilings, gabrons (rock-filled steel cages), bridging, rock bolts, dewatering seals, paving, evaporation and freezing.

TSUNAMIS

Tsunamis are large ocean waves generated most commonly by submarine earthquakes. The waves can be up to 40 feet high and 600 miles apart from crest to crest. They can move at speeds up to 500 mph.

As a tsunami enters shallow water, wave velocity diminishes and wave height increases. At the shore, tsunamis can reach heights of over 100 feet. The waves are usually separated by

long intervals - from 15 minutes to a full hour - and continue to arrive for many hours. The third to eighth waves are the largest and are accompanied by great hissing, roaring and rattling. To an uninformed populace, these characteristics of tsunami waves can prove very treacherous. In the long interval following the first or second wave, people often rush to the beach to observe the degree of devastation and so are caught by subsequent, greater waves.

San Diego's coast is less vulnerable to tsunami hazard than the central or northern coast for several reasons. The coast is protected from remotely generated tsunamis by the relatively wide offshore "continental borderland" which acts as a buffer,dissipating the energy before it reaches shore. And, locally generated tsunamis, although potentially a greater threat, have never occurred within the 170 years of recorded history. San Diego's offshore area appears to be less seismically active than those known to generate tsunamis. According to Joy (1968:25), it would be entirely speculative to suggest at this time that any significant threat exists on the San Diego coast.

The largest tsunami to reach the San Diego coast was 4.6 feet, generated by the 1960 earthquake in south Chile. All past tsunamis which reached San Diego have been well within the normal tidal range. One source feels, however, that tsunami hazard has been underestimated on the Southern California coast (Welday, pp. 13-15) because the great waves of both 1960 and 1964 happened to strike at low tide. The May 22, 1960 tsunami was occasioned by the earthquake at Valdivia, Chile, and caused damage from San Diego Bay to Santa Barbara, variously estimated to total from $.5 to $1 million. Welday points out that had these tsunamis reached the southern California coast at high tide, the wave height would have

been linearly increased, but the damage would have been exponentially greater. He insists that tsunami hazard must be calculated in terms of high tide occurrence (Welday, pp. 23-24).

Not enough is known about San Diego's offshore faults to be certain that a locally generated tsunamis will not occur. For example, if the San Clemente Island Fault, which has shown activity in recent years, and the active Aqua Blanca Fault, which leaves the Mexican Coast near Punta Banda, are actually a single larger feature, it could represent a standing threat to the San Diego coast line (Joy 1968:25).

Present knowledge of San Diego's offshore indicates that severe damage from remotely or locally generated tsunamis is unlikely. However, coastal bays and harbors are subject to moderate damage from the strong horizontal currents and seiches generated by tsunamis. Lowland areas, which are threatened by high tides of 7 or 8 feet or any origin, are also subject to moderate damage from flooding, beach front areas such as Oceanside, Del Mar, La Jolla Shores, Mission Beach, and Imperial Beach.

SHORELINE EROSION

All of the beaches on the San Diego coast are losing sand; it is only the rate of loss that varies. Sand loss in San Diego is due to several factors. One of the more important is the relatively dry climate of the recent past. Precipitation has not initiated the erosion of sediment along inland streams and subsequent flushing of the streams to the ocean. However, if there were sufficient rainfall, the flood control dams and debris basins would prevent the sediment from reaching the ocean. The problem of dwindling

sand supplies is aggravated by sand mining. An annual average of 2.4 million cubic yards of sand has been mined in the County since 1968. This compares with the estimate that an average of 530,000 cubic yards of material is deposited by rivers on the entire county coastline. In other words, an amount equal to 20% of the sand mined each year is deposited on the beaches by natural processes.

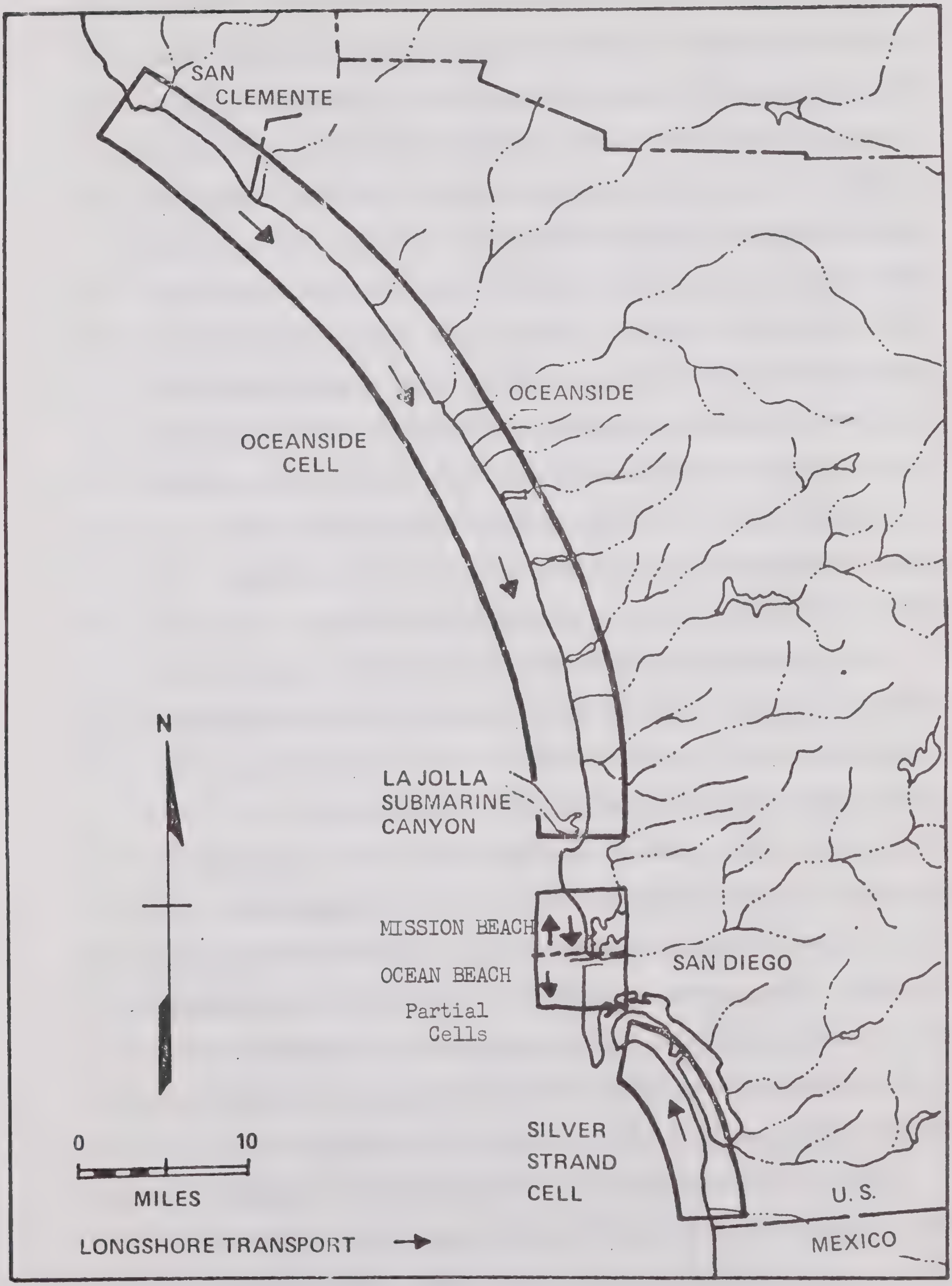
Beaches are also losing sand because of shoreline engineering structures which prevent the sand from moving laterally along the coast. The classic example of this is the Oceanside Harbor. Before the Oceanside Harbor and Del Mar Boat Basin were constructed, there was a wide sandy beach at Oceanside. Now, however, the beach is entirely covered with cobblestones. The cobblestones are covered only when the dredge spoil from Oceanside Harbor is pumped onto the beach. But the first winter storms usually wipe out all of this material.

Solutions to the problem of shoreline erosion begin with an understanding of natural sedimentation regimes on the coast. There are three separate littoral "cells" on the San Diego coast illustrated in Figure 3.

The Oceanside cell extends 66 miles from Dana Point to the La Jolla submarine canyon. It includes San Onofre, Camp Pendleton, Oceanside, Carlsbad, Leucadia, Encinitas, Cardiff-by-the-Sea, Solana Beach, Del Mar, and Torrey Pines beaches. The beaches are backed by 40 to 150 foot mesas except where interrupted by 8 partly filled estuaries. The mesas are composed of sandstone, siltstone, and mudstone overlain by marine terrace deposits.

FIGURE 3

LITTORAL CELLS IN SAN DIEGO COUNTY



Source: Nordstrom, C. E. and Inman, D. L. 1973:126

These beaches are fed by coastal streams from Orange County to Penasquitos Lagoon including: San Juan Creek; San Onofre Creek; the Los Pulgas, Santa Margarita, and San Luis Rey Rivers; Buena Vista, Agua Hedionda and San Marcos Creeks; San Dieguito River, Escondido Creek, and Los Penasquitos Creek. The total sand supply from these drainage basins is estimated to have been about 590,000 cubic yards per year under previously existing natural conditions (Chamberlain 1960). However, many of these streams enter coastal lagoons that trap part of their sediment load. Taking lagoon sedimentation into account, Nordstrom and Inman (1973:125) reduced the estimate of sediment contribution to 350,000 cubic yards per year. This estimate does not include sediment contributed by cliff erosion or leakage from other cells. Because of scant data, these sand supplies are nearly impossible to estimate.

The La Jolla submarine canyon is the Oceanside cell and sink. Sand piles up at the head until it is periodically swept down the canyon and carried 15 miles offshore to the San Diego Trough. The canyon traps approximately 260,000 cubic yards per year (Chamberlain 1960). Under natural conditions, then, the annual sand supply exceeded the annual sand loss. The surplus sand, about 100,000 cubic yards per year, was stored on beaches within the cell. Today, however, many of the streams feeding the Oceanside cell are dammed and Norris (1964) calculated that sediment reaching the ocean within the Oceanside Cell has been reduced by 33%, an average annual supply of 230,000 cubic yards per year.

However, the amount lost down the canyon remains 260,000 cubic yards per year. The difference is made up from sand stored on the beaches. Nordstrom, Greehan, and Inman (1973) estimate

that all of the beaches in the Oceanside cell will be devoid of sand in about 25 years if present conditions continue. This figure was calculated by dividing the volume of sand on beaches within the cell by the rate of sand transport, estimated at 260,000 cubic yards per year. 25 years is the life span of the beaches at the downcoast end of the cell; beaches at the upcoast end will be eroded earlier and the depletion will be more obvious during the winter months when the sand is stored offshore.

The second littoral cell on the San Diego coast is the five mile long Mission/Ocean Beach cell. The sources of sediment for the cell are the San Diego River, Rose Creek, and Mt. Soledad wet weather streams. Currently, they supply about 120,000 cubic yards per year. The sand sink for the cell are the jetties to Mission Bay. Sand accumulates behind both jetties so the jetties have essentially cut the cell into two units. Pacific and Mission Beach comprise the northern half and Ocean Beach the southern half.

The third littoral cell on the San Diego coast is the 12 mile Silver Strand Cell. The cell extends from Coronado to the Tijuana River. Beaches in this cell are seriously eroding. Even under natural conditions, the rate of sand transport exceeded the annual sediment supply (Nordstrom and Inman, 1973:128). Today, Rodriguez Dam has worsened the problem. Tijuana River is the source of sand for the cell and the river's sediment is divided between northerly longshore transport and southerly longshore transport along Playax de Tijuana (Nordstrom, Greehan, and Inman, 1973). Under natural conditions, the river supplied 660,000 cubic yards per year of sediment

(Nordstrom and Inman, 1973:127), but Rodriguez Dam now traps 72% of the Tijuana River sediment load (Norris 1964); thus, only about 180,000 cubic yards per year reach the ocean.

The sand sink for the cell is the offshore area at the tip of Zuniga Jetty. "The sand is apparently diverted offshore by Zuniga Jetty and by tidal currents in the entrance to San Diego Bay, where it is being deposited over a relatively large area offshore. A comparison of surveys made in 1923 and 1934 of this offshore area indicate that approximately 2,000,000 cubic yards per year of sand is being deposited in the offshore area." (Nordstrom and Inman, 1973:128). The amount of sand accreting off Zuniga Jetty exceeds the amount supplied by the Tijuana River by about 1,800,000 cubic yards per year.

The rate of longshore transport has been estimated by Nordstrom and Inman (1973) and by the U.S. Army Corps of Engineers (1970). Nordstrom and Inman based their estimate on the rate of erosion of dredge spoil placed on the beaches. Between 1940 and 1946, 28,000,000 cubic yards of spoil were placed on beaches in the Silver Strand Cell. By 1954, eight years later, 11,000,000 cubic yards had washed off. Thus, an average sand loss of 1,400,000 cubic yards per year. A comparison of beach profile surveys of Silver Strand Beach shows that about 1,000,000 cubic yards per year is being lost (House Document 399, 1955). (The U. S. Army Corps of Engineers [1970:F-15] estimate that the longshore transport rate is only 115,000 cubic yards per year.) Nordstrom, Greehan, and Inman (1973), assuming the 1,000,000 cubic yards per year rate, calculated that with the present

supply of sand and rate of transport, in six years, the beaches in the Silver Strand Cell will recede 100 feet from the MSL. Since net transport is to the north, beaches at the south end will erode first. Imperial Beach is nearly devoid of sand today and Silver Strand beach is retreating.

There are several potential sand sources for replenishing our beaches. They include mining sand from offshore deposits, mining sand from harbors, bays, and lagoons, mining sand trapped by dams, mining sand now trapped by submarine canyons, and mining inland sand sources.

Engineering structures designed to decrease the rate of sand movement are another method for preserving sand on the beaches. For example, the U.S. Army Corps of Engineers have proposed a submerged offshore breakwater for Imperial Beach. The breakwater would dissipate wave energy before it reached the shore, and, if successful, would prevent sand from drifting along the coast. This concept has been tried in Israel and although the breakwater traps sand and extends the one portion of the beach, it does so at the expense of the adjacent beach area which is deprived of sand and erodes. Thus, such techniques may resolve local problems but should not be permitted unless sand is imported to compensate for the sand trapped.

Coastlines with gentle slopes can be extended with fill to make the beach wider. Because the slope of the new "perched beach" must be somewhat steeper than the original so that it converges on the old slope line, a coarser grain deposit must be used to maintain stability. The creation of large artificial

spits is another possibility for adding more beach area. This has been proposed along the Santa Monica beach.

As ocean waves pound against the shoreline, they attack seacliffs through 4 major processes: (1) corrosion, the chemical weathering that results from contact with seawater; (2) corrasion, the mechanical action of waves laden with sand grains, pebbles, boulders and debris; (3) attrition, the breaking up by wave undercutting of materials fallen from the cliff face; and (4) hydraulic action, the hydraulic compression of air waves. This hydraulic action is probably the most effective agent of seacliff breakdown, since the sudden pressure changes enlarge voids in the cliff face and loosen the rock. The mechanical force of corrasion, however, can be immense, particularly in storm periods: storm waves on the Atlantic coast of France were observed to hurl 7,000 pound boulders over a 20 foot wall (Bascom, August 1959, p. 8).

A further kind of erosive force is exerted by shock pressure. When the water is sufficiently shallow to allow the breaking wave to trap a pocket of air between the bluff and the face of the wave, shock pressures of great force are set up that contribute to seacliff breakdown. These pressures have been recorded by dynamometer; a wave 10 feet high and 150 feet long, for example, had an observed pressure of 1,210 pounds per square foot, while values as high as 12,700 pounds per square foot have been recorded. It is this shock pressure that is utilized by surfboard riders just offshore, in the maneuver called "shooting the tube:" the surfer feels the pressure driving him like a

wind. Again, the resonant sound of "booming" waves is the impact of this air pocket on the cliff face rather than the wave itself.

Naturally, the type of rock or soil of which the coastal bluff is formed has a profound effect on the rate of erosion. On the California coastline, the highest observed rate of erosion has been 10 feet per year on the San Mateo coast. The rate of seacliff erosion is rarely uniform over time, however, as great storms can cause more loss of cliff face in a few hours than normal weather over a long period. Unconsolidated bluffs have been reported to have receded 40 to 90 feet overnight on the coast of England (King, p. 310). Shepard and Grant (1948) observed three differing rates of erosion on three adjacent wave-cut bluffs of silt and clay at La Jolla: only the heights of the bluff differed. During a 12 year period (1918 to 1930), bluff A, 21 feet high, receded 20 feet; bluff B, 33 feet high, receded 15 feet; and bluff C, 54 feet high, receded 10 feet. Kennedy (1973) found that approximately 75% of the Sunset Cliffs area had not eroded at all in the past 75 years; 20% of the area had undergone a small but measurable amount of erosion, and less than 5% had eroded rapidly (as much as 10 feet in the past 75 years).

Coastal areas of hard rock do not require further protection, as the resistance of the rock alone is sufficient to defer breakdown for a long period. Where the coastal cliffs are composed of non-resistant, erodible material, their natural defense is a fronting beach of adequate width. Such a beach serves as a buffer, absorbing the energy of the waves and preventing the ocean's direct access to the bluffs. Offshore topography can also influence wave patterns and reduce the impact of the surf's attack on the coastline.

Artificial methods of achieving a high, wide beach or offshore dissipation of wave energy include (1) mechanical replacement of eroded beach material (as at Port Hueneme); (2) construction of an inner bank of dunes between the cliff and the wave line, particularly when planted to a sand-loving cover such as marram grass; (3) construction of offshore groins or breakwaters. Direct protection of seacliffs is of course provided by construction of seawalls of loose boulders, solid masonry or concrete. As noted earlier in this summary, these artificial measures for seacliff protection must be carefully engineered in order to avoid beach erosion or shoaling.

GEOLOGIC HAZARD SAFETY MEASURES

In California at the present time, geologic hazard safety measures are generally scattered and voluntarily applied. Until the Alquist-Priolo Act, there was no mandatory compliance with any degree of standards, including the minimal criteria set forth in the Uniform Building Code, for any of the five major kinds of hazards considered here. The 1972 Act marked a significant step forward in providing some measure of statewide assurance of geologically safe development. However, the Act must be regarded as an initial step only, since it was concerned solely with active fault hazard.

Even within this limited scope, the Alquist-Priolo Act would appear to be less than adequate. The standards and criteria it establishes for earthquake safety are applicable solely within designated "hazard zones," which are directly related to fault traces (surface displacement), to known active subsurface faults correlative with areas of recorded earthquake experience. Safety

standards are then applied by degrees of zonal hazard. If, however, an overall high potential for seismic hazard within the coastal zone is predicted, the degree of hazard of any particular site is determined by the same procedure as for determining the local erosion pattern or the proneness to landsliding.

These impelling considerations have led to formulation of the policy proposals presented here for achieving geologically safe land use within the coastal zone, the general sense of which is establishment of an inter-disciplinary review board for coastal development. It is assumed that such a board would utilize to the fullest extent all related resources available from local, state and federal agencies.

In regard to area wide studies and maps, it should be pointed out that determination of some aspects of geologic hazard cannot be site specific. Determining erosion patterns and landslide proneness, for example, requires analysis of areas adjacent to a specific site. A small scale development, say a five unit apartment house, can be expected to justify geologic investigations of this extent, and jurisdictional resources must be available. The proposed permanent body would be expected to foster and utilize all such resources.

The findings and policies enunciated here will be seen to accord closely with the findings and recommendations of the Joint Committee on Seismic Safety, yet to be considered by the California Legislature. The two differ only in that scope of review activity proposed here is somewhat broader while at the same time the geographic area of consideration, being

necessarily coastal specific, is somewhat narrower.

It should be pointed out that a schedule of nominal fees for review could be utilized to provide most of the necessary financing, with any operating deficit to be supplied state funds, perhaps with federal assistance from the Land Use Policy and Planning Assistance Act of 1973, expected to be enacted by Congress sometime in 1974. In any case, the formidable scale of projected California losses from geologic hazard provides sufficient justification for an ambitious program of the kind proposed. By the year 2000, the California Division of Mines and Geology projects earthquake damage at $21 billion, landslide damage at $10 billion and tsunami damage at $41 million. If the approximate $1 million annual cost of a thoroughly adequate geologic hazard safety review board had to be entirely state-financed, it would appear to be a justifiable expenditure.

BIBLIOGRAPHY

(Only references cited in the Summary are listed here; a more complete bibliography accompanies the Technical Report)

Bascom, W., "Tsunamis", in Scientific American, 1954.

California Division of Mines and Geology, Urban Geology Master Plan for California, Bulletin 198, 1973.

California Division of Mines and Geology, "Sea-Cliff Erosion at Sunset Cliffs, San Diego", by Michael P. Kennedy. "California Geology" Feb., 1973.

California, State of, Final Report by the Joint Committee on Seismic Safety, 1970, pp. 1-225.

Joy, Joseph, 1968 - Tsunamis and Their Occurrence Along the San Diego County Coast. Westinghouse Ocean Research Lab, S.D. prepared for the Unified San Diego Co. Civil Defense and Disaster Organization. 1968.

King, C. A. M., Beaches and Coasts, Edward Arnold Ltd., London, 1959.

Lough, Charlie, "Stability of Cliff Near Sea Cliff Park and Self-Realization Fellowship, Encinitas" Report to the County Engineer.

Moore, David G., "Origin and Development of Sea Caves" National Speleological Society Bulletin 16, 1954.

Moore, George W., "Offshore Extension of the Rose Canyon Fault, San Diego, California", in Geological Survey Research, 1972, Chapter C. U.S.G.S., Professional Paper 800-C, 1972, pp. C113-C116.

Nordstrom, C. E. and D. L. Inman, 1973, "Beach and Cliff Erosion in San Diego Co., Calif." in Studies on the Geology and Geologic Hazards of the Greater San Diego Area, San Diego Assoc. of Geologists, San Diego.

Nordstrom, C. E., G. Greehan, D. L. Inman, 1973 "Shore Processes and Coastal Planning Criteria for San Diego Co." prepared for the San Diego Comprehensive Planning Organization.

Norris, R. M. 1964 "Dams and Beach Sand Supply in Southern California", Papers in Marine Geology R. L. Miller, ed. Mac Millan Co., New York p. 154-171.

U.S. Army Corps of Engineers, Beach Erosion Control Report: Cooperative Research and Data Collection Program of Coast of Southern California, Cape San Martin to Mexican Boundary, 1967-1968-1969, December 1970.

Welday, E. C., "Tsunami Hazards on the Orange County Coastline" Study Prepared for Orange County Co-op, 1973.

Ziony, Joseph I. "Recency of Faulting in the Greater San Diego Area, Calif." Studies on the Geology and Geologic Hazards of the Greater San Diego Area, Calif., 1973.

BIBLIOGRAPHY

(Only references cited in the summary are listed here; a more complete bibliography [illegible])

Bascom, W., "Tsunamis", in Scientific American, 1950.

California Division of Mines and Geology, Urban Geology Master Plan for California, Bulletin 198, 1973.

California Division of Mines and Geology, "Sea-Cliff Erosion at Sunset Cliffs, San Diego", by Michael P. Kennedy. "California Geology" Feb., 1973.

California, State of, Final Report of the Joint Committee on Seismic Safety, 1974, pp. 1-286.

Joy, Joseph, 1968 - Tsunamis and Their Occurrence Along the San Diego County Coast. Westinghouse Ocean Research Lab., Rpt. prepared for the Unified San Diego Co. Civil Defense and Disaster Organization. 1968.

King, C. A. M., Beaches and Coasts, Edward Arnold Ltd., London, 1972.

Lough, Charlie, "Stability of Bluff Near Sea Cliff Park and Soil [illegible] Following [illegible]" Report to the County Engineer.

Moore, David G., "Origin and Development of Sea Caves" National Speleological Society Bulletin 19, 1957.

Moore, George W., "Offshore Extension of the Rose Canyon Fault, San Diego, California", in Geological Survey Research, 1972, Chapter C. U.S.G.S., Professional Paper 800-C, 1972, pp. C113-C116.

Nordstrom, C. E. and D. L. Inman, 1973, "Beach and Cliff Erosion in San Diego Co., Calif." in Studies on the Geology and Geologic Hazards of the Greater San Diego Area, San Diego Assoc. of Geologists, San Diego.

Nordstrom, C. E., G. Gresham, D. L. Inman, 1973 "Shore Processes and Coastal Planning Criteria for San Diego Co." prepared for the San Diego Comprehensive Planning Organization.

Norris, R. M. 1964 "Dams and Beach Sand Supply in Southern California". Papers in Marine Geology R. L. Miller, ed. MacMillan Co., New York p. 154-171.

U.S. Army Corps of Engineers, Beach Erosion Control Report: Cooperative Research and Data Collection Program of Coast of Southern California, Cape San Martin to Mexican Boundary, Three-Year Report, 1967-1969, December 1970.

Weldy, T. C., "Tsunami Hazards on the Orange County Coastline" Study Prepared for Orange County Comm., 1973.

Ziony, Joseph I. "Recency of Faulting in the Greater San Diego Area, Calif." Studies on the Geology and Geologic Hazards of the Greater San Diego Area, Calif., 1973.